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X-Ray Determinations of Nitrogen and Oxygen Abundances in the O supergiants ζ Ori (O9.7 Ib) and ζ Pup (O4 If) from *XMM-Newton* RGS Spectra

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I wonder if maybe we should take Stan's name off the paper ? Then shoot him the draft & ask him if he wants to be included.

*Maurice & Jon both have 2nd affiliations. Take a look at Emma's paper too see what they are.

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And... since she helped w/ data analysis's advice, maybe we should include Véronique.

ABSTRACT {try to reduce the number of sentences that start with "we"

We present a method for benchmarking nitrogen and oxygen abundances of ~~the O supergiants ζ Ori and ζ Pup~~ using high resolution *XMM-Newton* reflection grating spectra. We use multi-temperature plasma emission models and properly account for absorption due to the partially optically thick stellar winds. We explore the sensitivity of our method to wind and ISM column density, radial ionization stratification, and temperature distribution ~~uncertainty~~. We find that, for these two stars, our abundances are relatively insensitive to these systematic uncertainties. We find nitrogen abundances of $\epsilon(N) = 7.92$ and $\epsilon(N) = 8.70$ for ζ Ori and ζ Pup, respectively. We find oxygen abundances of $\epsilon(O) = 8.72$ and $\epsilon(O) = 8.48$, respectively. These results support the ~~relatively~~ solar abundances of ζ Ori found ~~by most in the literature~~ and rule out the lowest and highest abundances for ζ Pup in the literature.

massive stars

And then add a separate sentence stating that we're applying this method to ζ Ori & ζ Pup

Key words: stars: abundances – stars: early-type – stars: massive – X-rays: stars

1 INTRODUCTION

Massive stars are a primary driver of nucleosynthesis within the galaxy. Their strong stellar winds and end states as supernovae return material processed in their cores to the interstellar medium. Surface abundance measurements are a key ~~indicator~~ diagnostic of mixing processes in the ~~core~~ stellar interior, and there is currently disagreement within the literature regarding these measurements (see e.g. Zhekov & Palla (2007), Bouret et al. (2012), Pauldrach et al. (2012)). Accurate determinations of surface abundances of massive stars are therefore important from both a stellar evolution and a galactic point of view.

In the CNO cycle, the ^{14}N to ^{15}O reaction has the lowest cross-section, bottlenecking the cycle at that stage and resulting in a buildup of nitrogen in the core. Rotational mixing models including meridional currents and turbulent diffusion as transport mechanisms from the core to the surface predict a positive correlation between surface nitrogen enrichment and rotational velocity. Surveys of B stars (Hunter et al. (2008)) and O stars (Rivero Gonzalez et al. (2012)) in the Large Magellanic Cloud indicate that the predictions of rotational mixing do not hold for approximately half of the surveyed stars. These results have necessitated reevaluation of classical rotational mixing. Unfortunately, relatively little has been published on O star abundances, and there is a significant disparity of results; for example, there is a factor of 15 difference between the nitrogen abundances of ζ Pup found by Zhekov & Palla (2007) and those found in Bouret et al. (2012).

As compared to the situation for late-type stars, abundance determinations of O stars is an underdeveloped field and the problem of CNO abundance determinations is a difficult one. Historically, optical and ultraviolet spectroscopy have been the dominant approaches (Herrero et al. (1998), Pauldrach et al. (2001), Bouret et al. (2008), Bouret et al. (2012), Pauldrach et al. (2012)). However, there are several difficulties inherent to optical spectroscopic determinations. Photospheres are complex and non-uniform, containing temperature, density, pressure, and ionization gradients. Further, many of the observed lines are transitions between excited states. These factors make optical spectra highly complex, and complicated non-LTE modeling is required for accurate determinations.

X-ray determinations may provide a ~~useful~~ and ~~reliable~~ alternative to optical determinations. X-rays are produced in shock-heated regions of the stellar wind, and the difficulties

throughout, use \citep to get rid of the extra parentheses around the year

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